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**Estimating Situational Awareness Parameters
for Net Centric Warfare from Experiments**

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Abstract

During the past decade the doctrine of Net Centric Warfare has emerged and grown. NCW has been defined as an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and degree of self-synchronization. (Alberts, Garstka, and Stein (2000)). Situational Awareness and its sharing by linked warfighters is thus deemed to be a major causative factor in increasing combat power. How do we create and measure situational awareness and relate it to combat? What are some of its determinants? We shall see in the results of the controlled warfighting experiment examined below that there are at least two major determinants of increased Situational Awareness for a warfighting team, viz. use of a relatively complete Common Operational Picture of the battlespace and time spent collaborating with this COP as a team.

Approach

In the approach adopted here, variable Situational Awareness was experimentally created in a team context in a series of Human-In-The-Loop (HITL) experiments and, via the Common Operational Picture (COP) prototype, related to combat outcome. In the first experiment three warfighting teams each composed of a retired flag officer and a pair of ship captains played out four battles, composed of two versions of a Persian Gulf air/sea combat scenario crossed with two versions of information technology, the COP prototype fed by national and organic sensors and the control ensemble with the ship captains having only local pictures fed by organic sensors and the flag officer having only the national sensor fed big picture. The mission of the teams, including the two ship captains protecting oil platforms in the Gulf, was to identify and to prosecute advancing enemy fast attack craft. For all three newly created teams and for all four trials, Situational Awareness (SA) was defined as the proportion of the crisis relevant (or mission critical) set of warfighting platforms (red, blue or neutral) correctly identified as important by the commander. During the simulated combat operation, using the RESA wargame simulator, the commander's realization of the situation, his Situational Awareness, was obtained by his indication on a map of the platforms he deemed important at that time, i.e. by his personal Cognitive Operational Graphic (COG). The commander's proportion correct was then obtained by comparison with the platforms on the simulator's Ground Truth map at the same time. Such COG measures were obtained from all commanders at the end of each of the three phases of each of the combat scenarios. Thus greater overlap between the commander's COG and Ground Truth was indicative of greater Situational Awareness by the commander at the time.

We hypothesized (1) that use of the COP by a warfighting team causes significant improvement in their Situational Awareness. (Hiniker & Entin, 1990, pg. 220) Indeed, teams using the COP prototype achieved on average nearly 10 percent better Situational Awareness than control teams, i.e. COP teams correctly identified, on average 58 percent of the crisis relevant combat platforms throughout the combat scenarios compared to only 53 percent for control teams. This is a significant difference favoring use of the COP ($t =$

3.06 for 5 degrees of freedom with paired comparisons, $p < .05$). Based upon the sample size and variability in these results, we can be 95 percent confident that the true difference in Situational Awareness between the two technologies is positive for the COP and lies between 1 percent and 9 percent.

More recently, there has been expanded work on the concept of Situational Awareness and Shared Awareness (Perry, Signori & Boon, 2004) which has alerted us to an additional factor among the causes of improved Situational Awareness, and for which we find compelling evidence in secondary analysis of our experimental data. This variable, (T), is time spent by a warfighting team in collaboration with a COP, complete or incomplete. Perry et al define Situational Awareness as “(a warfighter’s) realization of the current situation based on the observed CROP (Common Relevant Operational Picture)”. Similarly, they define completeness of the CROP as “the degree to which the information is free of gaps”; and correctness as “the degree to which information agrees with ground truth.” Our original approach is in full accord with this terminology. What is added here is their plausible hypothesis on “team hardness”, that the completeness of the (team) system for recording and retrieving information (thus improving the team’s Transactive Memory System (TM(T)) depends upon how frequently the team has recently collaborated (T). They define $T = t + \tau$, where t represents the time elapsed since the start of the operation and τ represents the length of time the team has been training or operating together. (Perry, Signore & Boon, 2004,pg. 79). Their model treats the strengthened Transactive Memory System as a major contributor to Situational Awareness. Both t and τ , hence T , are present and measurable in our data for the teams we created for the first COP HITL experiment. Thus, we hypothesize (2) that increased time spent by a team collaborating with the COP (T) causes increased Situational Awareness (SA) in team members.

Results

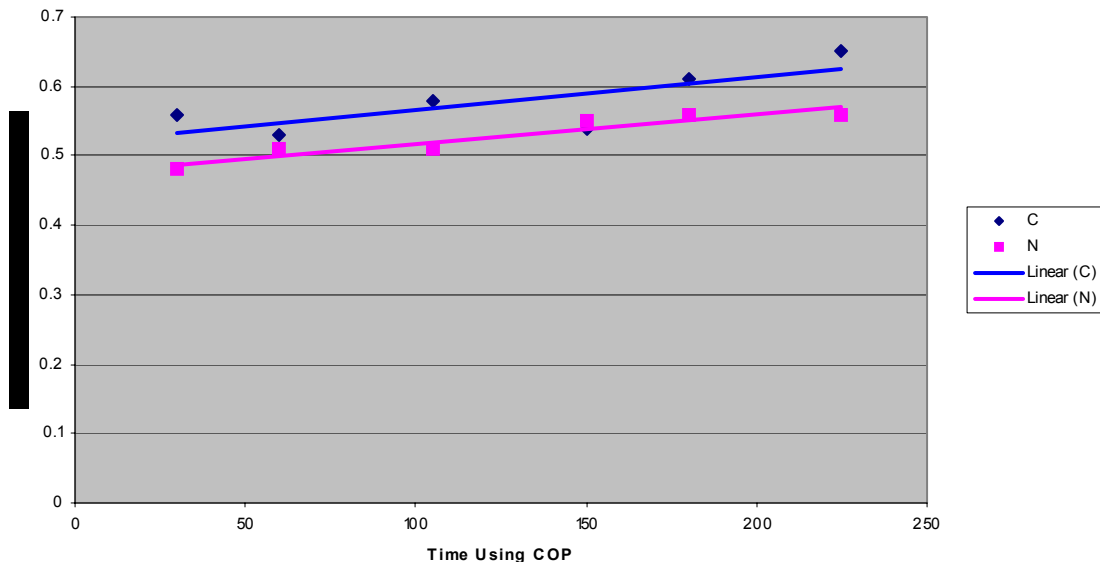
Examination of Table 1, below, will help define T in the context of our experiment.

TABLE 1. Degree of Situational Awareness for Members of Warfighting Teams under COP and no-COP Conditions by Time Order of Observation.

| Sequence of Observations | COP | no-COP | Delta |
|-----------------------------|-----|--------|-------|
| I 1 | .56 | .48 | .08 |
| I 2 | .53 | .51 | .02 |
| I 3 | .58 | .51 | .07 |
| II 1 | .54 | .55 | -.01 |
| II 2 | .61 | .56 | .05 |
| II 3 | .65 | .56 | .09 |
| Average | .58 | .53 | .05 |

Each of the 12 data points in the table is an average of the 18 Situational Awareness scores obtained from all three officers from all three teams for both warfighting scenarios. Since each team played all four conditions (COP/not-COP, Scenario A/Scenario B), each team used the COP twice, once with each of the two scenarios. A team's first use was termed Replication I and their next use, Replication II. In addition, within each Replication, during the trial scenario run, there were three SA data takes at roughly 30 minute intervals, yielding the measure of t . Since we created these teams from scratch in the lab, T is precisely measurable in the context of the experiment. Thus in Replication I, $T = \sum t_i$; in Replication II, $T = \tau + \sum t_i$, where $\tau = 2$ hr., from experience in the previous trial. This combination of two Replications and three scenario time phases results in the ordering of data presented in the successive rows of Table One. Thus the Sequence of Observations column in Table One corresponds to T as measured by time spent working with teammates using the COP or COP surrogate (not-COP). The values for T (in minutes) beginning with I 1 through the six observation points to II 3 are: 30, 60, 105, 150, 180, 225 minutes of team learning. Figure 1 below depicts a recasting of the results for Situational Awareness in Table 1 while incorporating the variable T .

Figure 1. Degree of Situational Awareness by Time Using COP for COP and Partial COP Conditions



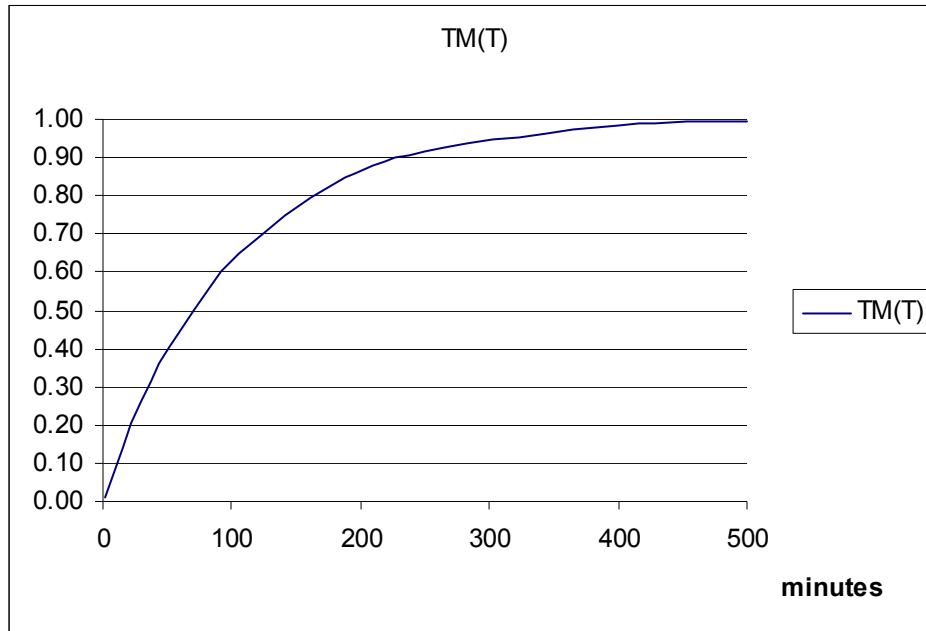
The results depicted in Figure 1 provide strong support for Hypothesis (2) that increased time spent by a team collaborating with the COP (T) causes increased Situational Awareness (SA) in team members. For the two curves combined ($n = 6$), the overall correlation between T and SA yields $r = .95$, $p = .003$. Examining the correlation within the two particular technologies, the top curve smoothly linking the data points for SA in teams using the COP for increasing T affords a modestly strong correlation ($r = .76$, $p = .07$) between SA and Time collaborating with the COP. The linear equation for the best-fit line is $SA = .52 + .0004752 T$, with a Standard Error of the Estimate of .03. The bottom curve smoothly linking data points for SA for teams in the not-COP condition for increasing T provides an even stronger correlation ($r = .95$, $p = .004$) between SA and

Time using the (partial) COP. In the not-COP or Partial COP condition, each of the two ship captains had only his local tactical picture fed only by his ship's sensors and the admiral had only his big picture fed by national satellites. This distributed team relayed information to each other via voice communications. The linear equation for the nearly parallel best-fit line for this not-COP condition is $SA = .475 + .000425 T$, with a Standard Error of the Estimate of .01.

In sum, combining the findings for this particular experiment we find a simple linear model that accounts well for the results. We might term this the Tech Team Model of Situational Awareness, emphasizing the fact that we are examining the behavior of a socio-technical system where the COP serves as a kind of partner in the team. In other words, for a team using a partial assemblage of local tactical pictures, begin with Situational Awareness of 47.5 percent of relevant battlefield platforms; for a team using a more complete COP, add 4.5 per cent, yielding an initial Situational Awareness of 52 per cent. Thus the effect of the relatively complete COP is to lift the initial level of Situational Awareness of team members. Then for a team equipped with either technology, augment their Situational Awareness by 2.5 per cent for every hour they spend collaborating as a team with the COP. Bear in mind when extrapolating to other situations that these data were collected over a short, roughly four hour, time period. For longer time periods, the damping effect of the standard learning curve will undoubtedly come into play.

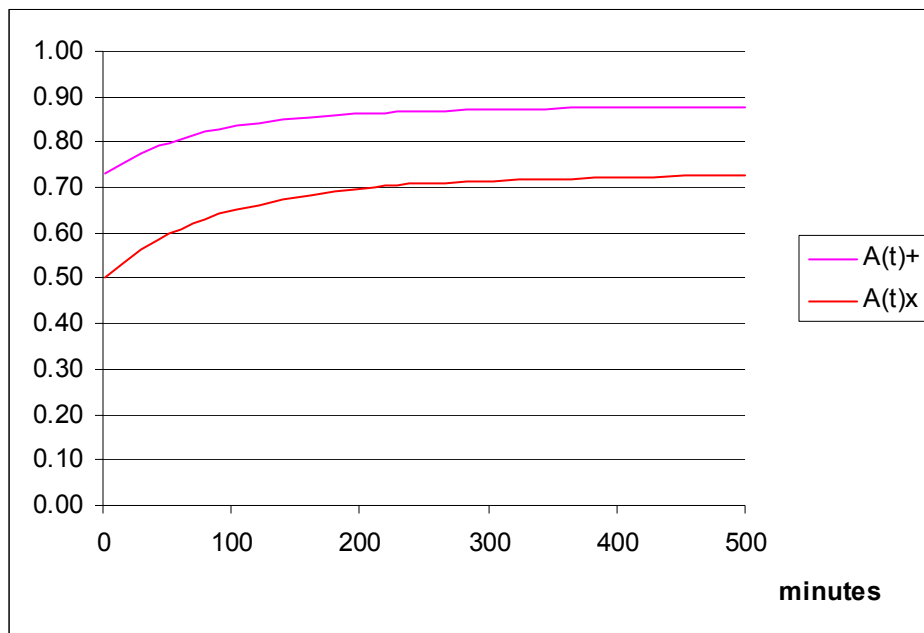
We can get a glimpse of some more general considerations, including likely learning curve effects, by examining the Perry model in more detail. Here the first consideration is to relate the strength of the transactive memory system, $TM(T)$, of the team to time spent collaborating with the COP, T . They propose the logistic curve function, otherwise known as the learning curve or growth curve: $TM(T) = 1 - e^{-aT}$, where a is a steepness of slope parameter. Figure 2 below depicts this curve for our time frame with $a = .01$. We selected this low value because higher values provide a steeper learning curve than seems warranted by our data.

Figure 2. Model Relationship between Strength of Transactive Memory System (TM (T)) and Time Spent Collaborating with the COP (T)



The next consideration is to relate Situational Awareness, here $A(T)$ to $TM(T)$. Here, again, they propose an exponential relationship: $A(T) = e^{K + TM(T)} / 1 + e^{K + TM(T)}$, where K is a parameter representing the product of many value added factors including the completeness of the COP. Since the COP/ not-COP condition is represented in the Perry model by the parameter K , we have chosen to set $K = .98$ for COP and $K = .02$ for not-COP to attempt to achieve a large spread effect for Figure 3 below. The exact value for K , interpreted here as completeness of the COP, was not measured beyond the ordinal scale in this experiment, although it is entirely feasible to take more precise measurements of completeness of the COP in future experiments.

Figure 3. Dynamic Model Relationship between Situational Awareness, $A(T)$, and Time Spent Collaborating with the COP (T).



The upper curve is for $K = .98$ in the original dynamic model. Setting $K = .02$ shows no apparent impact by comparison, and this curve is not included in Figure 3. The lower curve modifies the relationship of the exponents in this model from the proposed summing of K and $TM(T)$ to a modified version involving multiplication of the two exponents, which effectively lowers the overall value of the exponent. As the reader can see, the modified version of the dynamic model yields a somewhat closer fit to the experimental data points. Never-the-less, 83 percent of the 12 experimental data points fall below 60 percent Situational Awareness; whereas the vast majority of the prediction points from either of the model versions are above 60 percent. Thus neither version of the dynamic model fits the data nearly as well as the simple linear model depicted in Figure 1.

Discussion

Situational Awareness is deemed a major causal factor for improved combat effectiveness for the warfighter involved in Network Centric Operations. We have demonstrated here through controlled experimentation that use of a relatively complete COP by members of a warfighting team causes improved Situational Awareness and that this Situational Awareness is further improved in proportion to the amount of time the warfighting team spends in collaboration using the COP. A linear “Tech Team” model of Situational Awareness which fits these data has been advanced here; and it accounts well for the findings within the short time span of collaboration examined. It seems obvious that there exists a point in collaboration time where further time spent in collaboration by the warfighting team would have diminishing effects on improving Situational

Awareness. Such an inflection point is best ascertained by further controlled empirical investigations.

While we have experimentally demonstrated a couple of causes of Situational Awareness, as Perry and others have pointed out, there undoubtedly remain several other determinants of Situational Awareness (See Perla, 2000). The Perry value added model is quite comprehensive and includes factors on the technical transmission of quality information to the warfighting team as well as additional social/cognitive factors such as different “feature vectors” comprising the COP and the varying individual interpretive capabilities of team members.(Perry et al, 2004). Furthermore, moving from individual Situational Awareness to Shared Situational Awareness requires additional modeling considerations combined with controlled empirical investigation. (See Hiniker, 2000; Hiniker, 2002; and Perry et al, 2004).

One additional factor which undoubtedly impacts Situational Awareness is information overload. As the number of warfighting platforms, red, blue and neutral, involved in a combat scenario increases and as their speed and complexity of movement over time increase, the capacity of any warfighter to comprehend the situation will at some point be exceeded, and his Situational Awareness will suffer as a consequence. We are developing new information technologies for the warfighter, such as Blue Force Tracker and the User Defined Operational Picture. All these technologies will bring more detailed information to the warfighter. Where is the point at which the warfighter becomes overloaded? And how does it vary across warfighters and teams of warfighters engaged in Network Centric Operations?

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